# Twenty years is too long – practical engineering approaches to materials substitution


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# Report Documentation Page

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# THE PROBLEM

# The Problem

- Many of the materials and coatings we currently use must be replaced for regulatory or performance issues
  - Cd plate, chromate processes and materials
- We used to be able to plan since the needs were obvious (even though the changes were glacial)
  - Although obvious changes rarely made until there is no choice
- It historically takes 20 yrs to go from lab to market
  - Often materials used commercially for years before qual even begins for aerospace and defense
  - Regulations  commonly give only 5 years
  - Strategic materials shortages can occur even more quickly
- How can we do this much faster, with low risk, and better performance?

ASETS DEFENSE
ADVANCED SURFACE ENGINEERING TECHNOLOGIES FOR SUSTAINABLE DEFENSE

# Why does it take so long?

ESTCP
SERDP

Concept development, material identification

Material, process development, initial test data (e.g. SERDP)

Qual testing

OEM authorization

Problem is system safety. Must have acceptable performance, life. New solutions must play well with other system components.

Testing, validation (e.g. ESTCP)

Service testing, qualification (item by item)

Legacy authorization

Diffusion, industrialization (OEM, Depot)

Years →

1 5 10 15 20

# Tools for better and faster adoption

## Data-based decisions

- Engineering data, authorizations, implementations
- Experience with fielded systems
- Technology Analysis, Roadmaps

## Computational design

- Computational design of materials
- Computational design of coatings, treatments, systems

## Accelerated testing

- Test for performance, not equivalence
- Meaningful accelerated tests


# DATA-BASED DECISIONS

# Adoption and adaption of commercial products



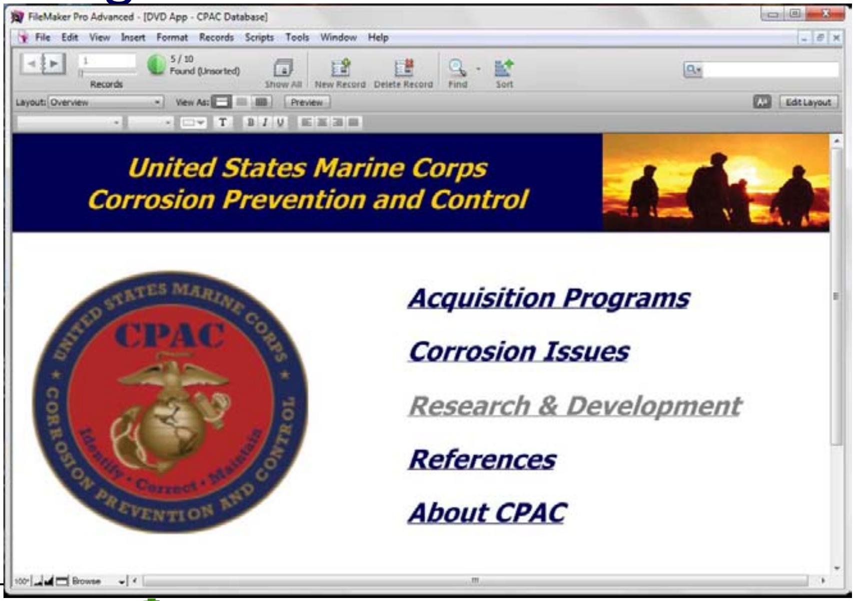
Data-based decisions

- A good answer is often already available
- Many aerospace and defense requirements are unique, but does not mean commercial products cannot be adopted or adapted
  - Car fasteners have used metal-filled dip spin polymer coatings for years, adopted for military vehicles
  - Powder coat and e-coat long used on lawn furniture, adopted for military vehicles works better than paint
  - ZnNi electroplates adapted from commercial vehicle and earlier aircraft coatings to replace Cd on military systems

# Efficient use of available data

Data-based decisions

- Available data often not used
  - USMC CPAC developing database to track corrosion problems and solutions in fielded vehicles
  - Feed data back into design



# Gathering engineering data, tracking successful usage

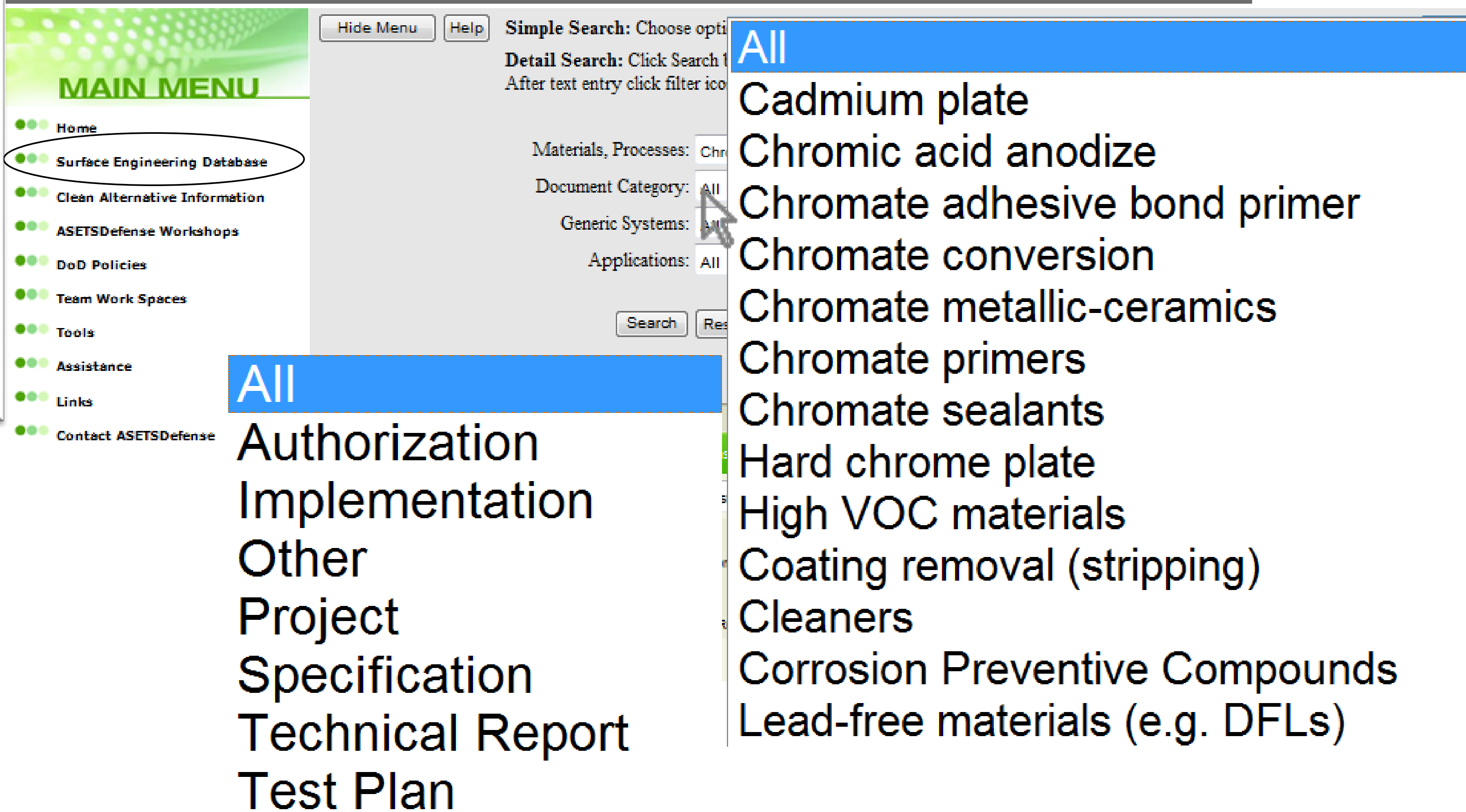




- ASETSDefense Surface Engineering Database is constantly updated to try to capture
  - High quality engineering data
  - Authorized technologies, materials
  - Implementations of clean technologies
- Scope
  - Not limited to DoD - military and commercial
  - Includes materials and applications from across the world

# ASETSDefense Database – Document types

Data-based decisions



# Roadmapping – e.g. Aerospace and Defense Roadmap, NASF

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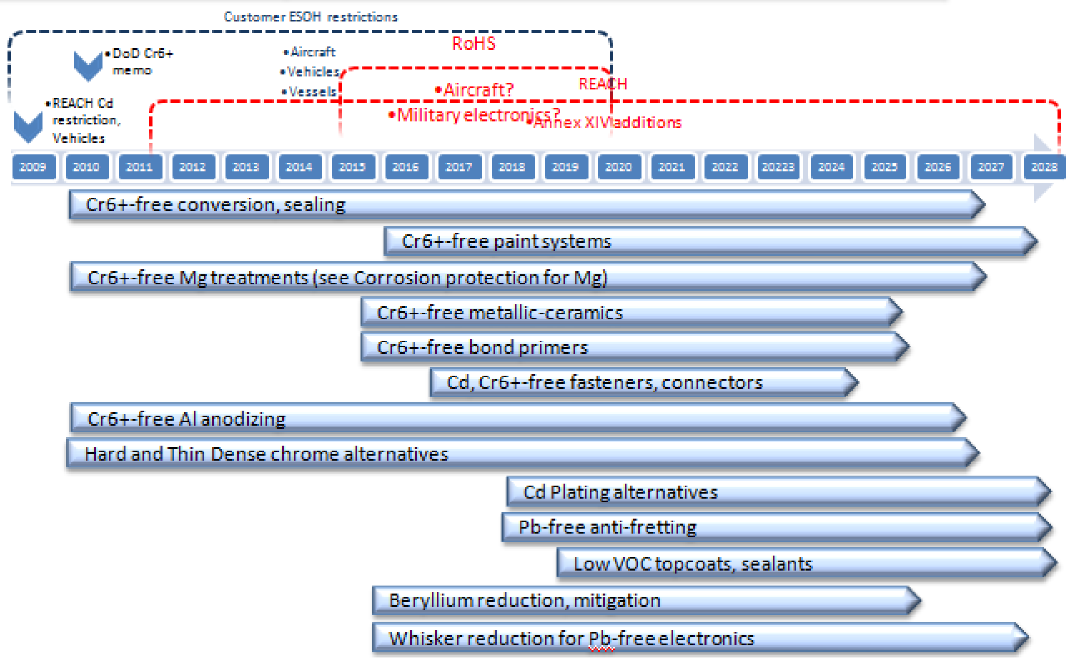
ESTCP SERDP

NASF NATIONAL ASSOCIATION FOR SURFACE FINISHING

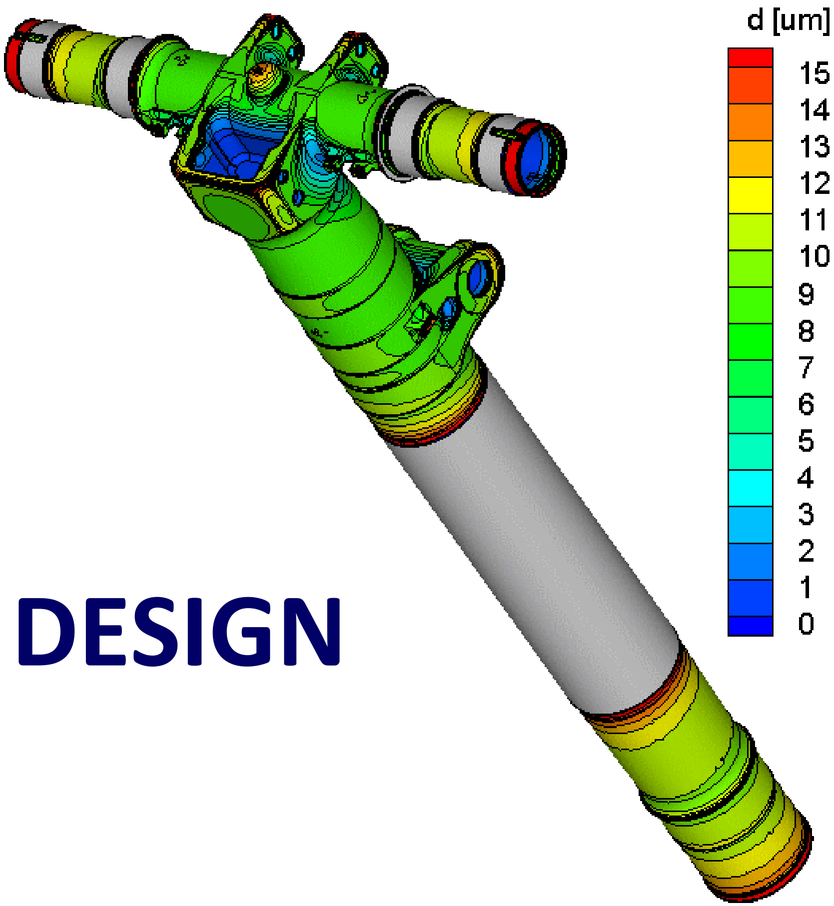
Data-based decisions

***Meeting ESOH regulatory requirements***

| Goals: | Routes: |
|---|---|
| $Cr^{6+}$ elimination from materials | Trivalent and non-chrome conversion coatings, sealers, paint systems, etc. |
| $Cr^{6+}$ process elimination | Non-Cr plating, anodizing |
| Cd elimination | Cd plating alternative adoption |
| Pb elimination from anti-fretting coaitngs | Pb-free alternatives |
| VOC reduction | Low VOC topcoats, sealants, etc. |
| Beryllium reduction, mitigation | Alternative materials (coated powders), isolation coatings |
| Whisker reduction from electronics | Solder modifications, mitigation coatings and treatments |




Combined with Technology Analysis of requirements and readiness, Roadmaps can be a useful tool to understanding current technologies and gaps




# COMPUTATIONAL DESIGN

Distribution A – Distribution unlimited

# Computational design



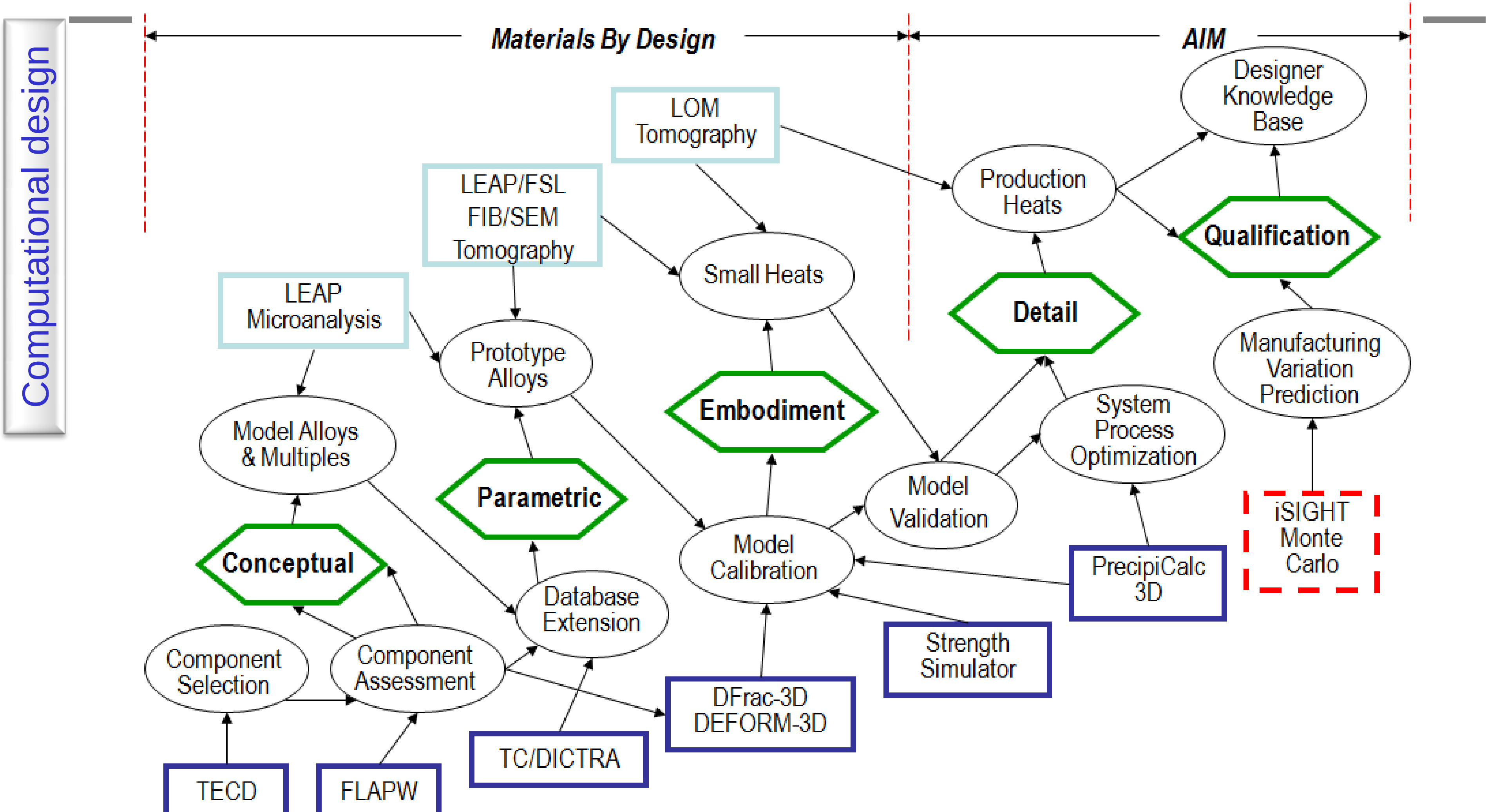


- Materials by Design™ (vs Materials by Luck)
- Databases and computational methods now permit us to design alloys from scratch
  - Development time months instead of years
  - Now being used for new alloy designs (e.g. CuBe alt)
  - Developed S53 landing gear steel, ASTM 5922
    - Came within a few % of targets right out of the box
    - Normal development would have taken several years


300M and Ferrium S53 A-basis *Minimum* Longitudinal Properties:

| | UTS (ksi) | YS (ksi) | El. (%) | RA (%) | Fcy (ksi) | Fsu (ksi) | Kic (ksi√in) |
|---|---|---|---|---|---|---|---|
| 300M | 280 | 230 | 8 | 30 | 247 | 162 | -- |
| S53 | 280 | 213 | 11 | 44 | 245 | 176 | 50 |

# Materials by Design – Questek Innovations



# Computational design also speeds up validation



- Accelerated Insertion of Materials
  - Computational methods also let us get “virtual test data” to fill in the gaps
  - If you design computationally you can link back into the test data to interpolate and extrapolate
  - Does not reduce data for A-allowables, but reduces test data needed for engineering
- Because coatings not thermodynamic equilibrium materials difficult to model
  - Need to develop computational methods for coatings

# Integration of materials data with CAD design

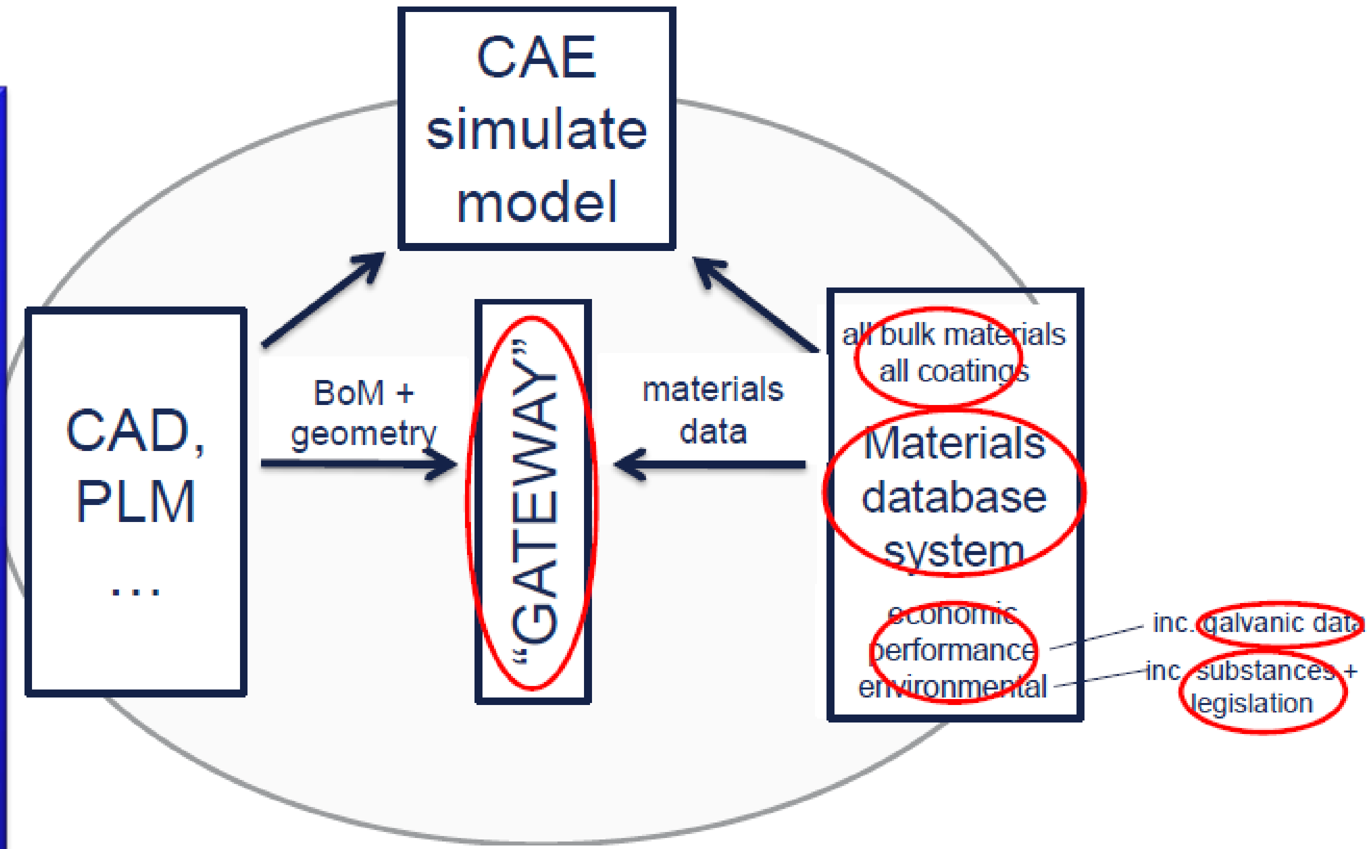
Computational design

- Successful use of computational methods also means that they must be integrated into the design software
- Design engineers currently use FEA for stress analysis, heat transfer, etc.
- New databases with CAD integration allow the designer to include performance of coatings, galvanic coupling, etc.
  - These new databases also provide the information needed for regulatory compliance

# Data and design integration – Granta Design

Computational design

Granta databases now combine alloy, composite, coating and surface treatment data, and ESOH compliance info.
Integrate with CAD software via standard data Gateway



# Computational galvanic design - Elsyca





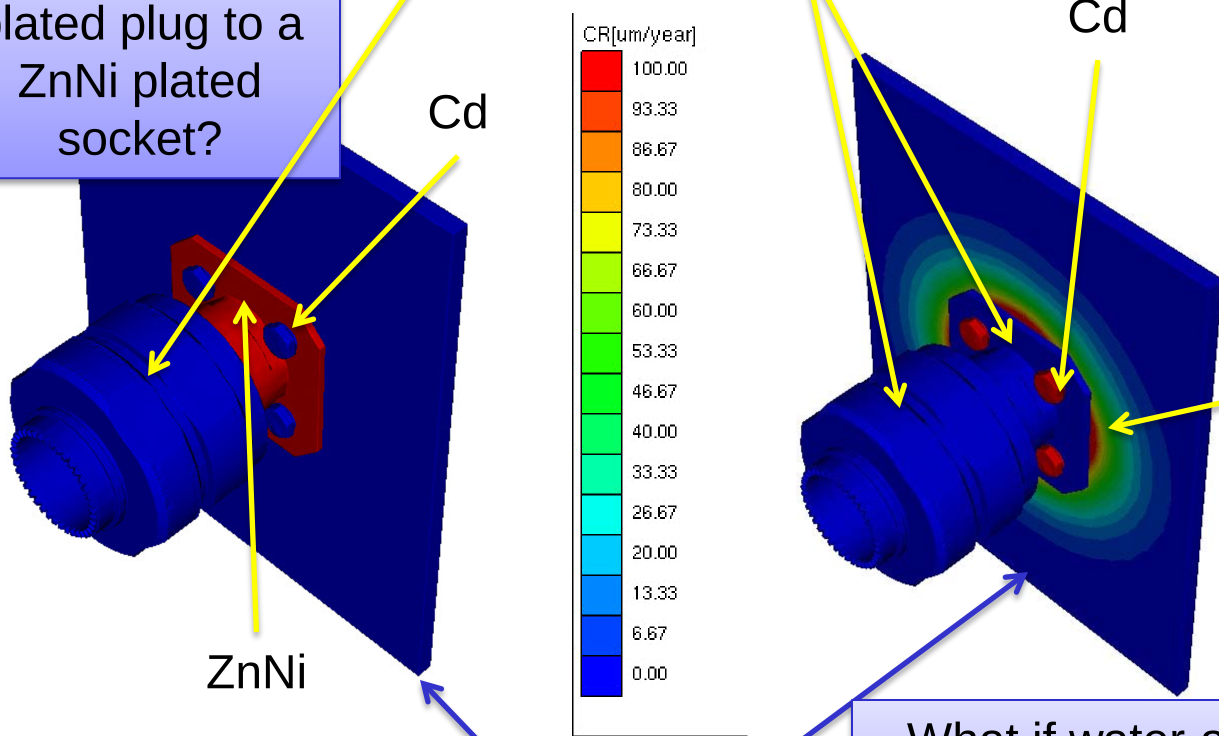
- Galvanic corrosion between disparate metals and coatings is still a major problem
  - There is a reason we have Ni-Cd batteries
  - The Ni-Mg battery is even better!
- Even bigger problem with new materials to save weight, meet ESOH requirements
  - C-fiber composites, Ti – very cathodic
  - ZnNi (cathodic), electroless nickel-PTFE coatings (anodic)
  - Chromate free conversion coatings/sealers
  - Metal flake-loaded gap fillers
- New software calculates corrosion rates by solving electrochemical equations
  - Does not yet take into account effects of corrosion, but permits non-expert to identify design problems

# Using computational galvanic design to make the right choices



Computational design

What if you connect an EN plated plug to a ZnNi plated socket?




Left: ZnNi on socket corrodes to protect electroless Ni on connector

Right: Al backplane corrodes right at socket

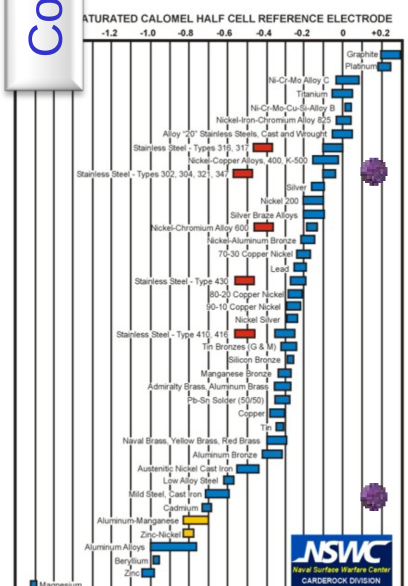
You can quickly "test" many scenarios risk-free

What if water accumulates around connector, not over whole backplane as in B117?

# New materials require new materials data

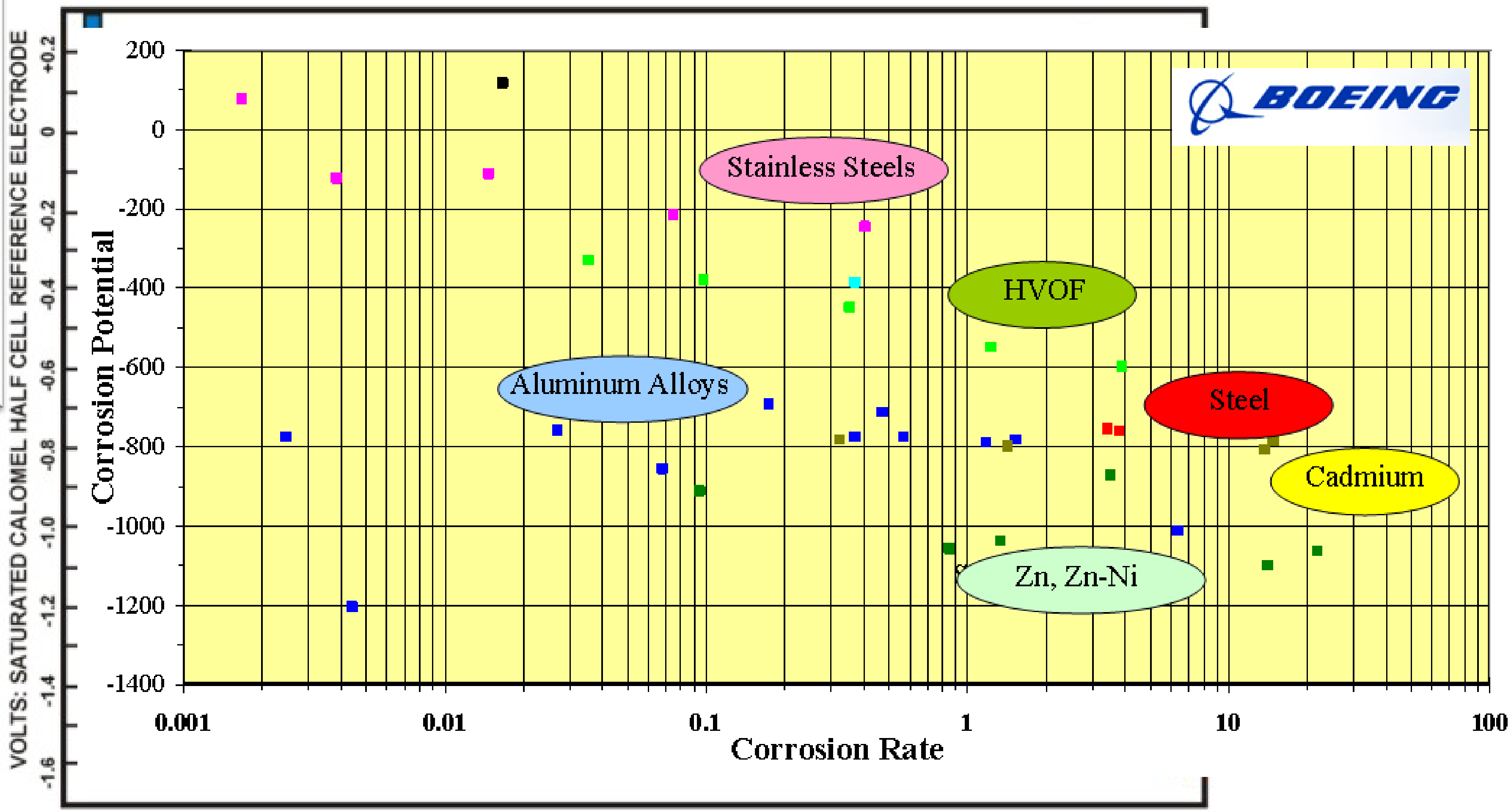
Computational design

- Existing data often half a century old
- Older coatings often lack critical data so we do not know what properties alternatives need
- Little or no reliable data on many new materials
  - Especially such information as galvanic data on new coatings with non-chromate finishes
  - Very limited data available for Cd alternatives and non-$Cr^{6+}$ sealers
- Measurement conditions often not relevant to how data are used
  - Galvanic chart 50+ year old data only for older alloys in flowing seawater, no new alloys and finishes in quiescent salt water relevant to aircraft
- We need reliable data for all our materials and treatments



# Computational design is only as good as the data it depends on

Computational design




# ACCELERATED TESTING

# More meaningful testing

- Most existing performance tests were developed for existing (old) products
  - Many new products work in a completely different way and often fail existing tests
    - Example – non-$Cr^{6+}$ conversion coatings
- Most requirements state that any alternative must be "equal to or better than" the existing material
  - The only material that meets that requirement in every test is the existing material – excuse not to change
- Tests we use for qualification are often explicitly not designed for that, but they are all we have
  - E.g. ASTM B117 for corrosion, F519 for embrittlement
- We need true performance tests based on real service requirements, rather than tests that simply compare with older materials

# Faster testing



- The slowest types of testing are
  - Corrosion – typical 2,000 hr salt fog, one year beach exposure test
  - Service evaluation – typical one or more carrier tours of duty, one or more years flight test
  - Endurance and wear testing – often several months
- We have accelerated test methods, but their relevance is questionable at best
  - B117 salt fog
  - Ring-on-block wear test
- We need short-duration tests that accurately predict long-duration real-life performance

# Accelerated corrosion testing



- Everyone agrees B117 not representative, was never intended for qualification
- Two SERDP projects to devise better tests
  - WP-1673, trying to design a method that includes all the variables that drive corrosion
    - Mimics the causes
  - WP-1674, trying to mimic in the lab the chemical changes we see in the field
    - Mimics the effects
- NAVAIR method combines short B117 or G85 with short beach test using galvanic assemblies
  - E.g. 500 hr B117 + 7 month beach

# Accelerated field testing

Accelerated testing

- USMC uses Accelerated Corrosion Durability Road Test (ACDRT) at Aberdeen Test Ctr
  - Uses LRIP vehicle
  - Daily driving cycle to match service conditions
  - Designed to be equivalent to 22 yrs service
  - Tear-down and evaluation
  - Easy to do with vehicles – a little more difficult and expensive with ships and aircraft!

# Conclusions

- With rational use of databases, computational tools, and technology analysis we can greatly reduce the development cycle
  - Using databases rather than reinventing the wheel
  - Meaningful, predictive tests that work for new materials
  - Valid performance data for new materials and coatings
  - Computational design methods for materials
  - Materials databases and modeling integrated with CAD for error-free design